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ABSTRACT

This document is designed to help integrate the skills of composing (writing) with the procedures and perspectives of New York elementary, secondary, and continuing science education programs. Sections are devoted to the composing process and its relationship to a science laboratory model, to techniques for evaluating writing, and to the spectrum of laboratory activities. Following a message to secondary school principals on the role of the laboratory in general and in fostering writing in particular, section 1 discusses the writing process (prewriting, writing, revising), a four-stage laboratory model (planning, performance, analysis/interpretation, and application), and integrating the laboratory activity model with the composing process. Section 2 presents teacher, peer, and self evaluation techniques, including a checklist to aid in the latter evaluation. Section 3 discusses different laboratory activities, commenting on manipulative experiences, information seeking, and making provisions for structure. The last section provides guidelines (including a checklist) for selecting laboratory manuals. (Author/JN)

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REFLECTIONS ON WRITING IN SCIENCE

WRITING PROCESS

LABORATORY INVESTIGATIONS

SCIENTIFIC INSIGHT

LABORATORY INVESTIGATIONS

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REFLECTIONS ON WRITING IN SCIENCE

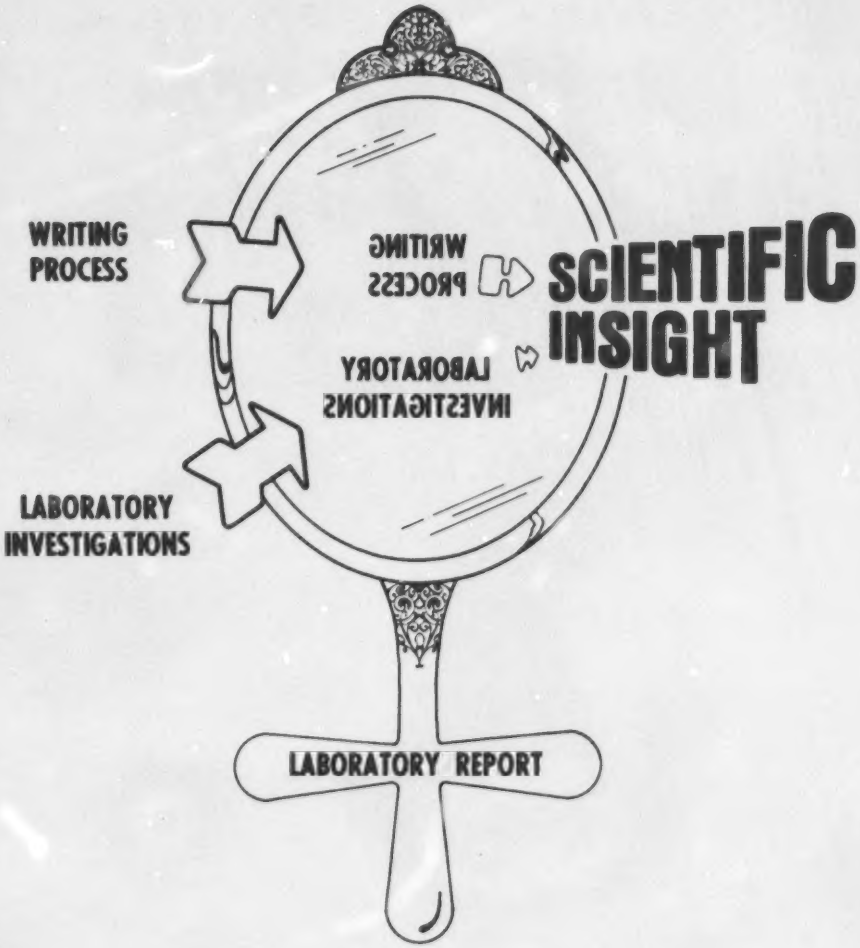

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TABLE OF CONTENTS

ACKNOWLEDGMENTS iii

INTRODUCTION 1

SPECIAL MESSAGE TO THE PRINCIPAL 3

THE COMPOSING PROCESS 5

A LABORATORY ACTIVITY MODEL 8

INTEGRATING THE LABORATORY ACTIVITY MODEL WITH THE COMPOSING PROCESS 11

TECHNIQUES FOR EVALUATING STUDENT WRITING 13

THE SPECTRUM OF LABORATORY ACTIVITIES 18

GUIDELINES FOR SELECTING LABORATORY MANUALS 24

BIBLIOGRAPHY 27

INTRODUCTION

An individual science course and the science teacher are particularly important resources for helping students achieve important goals of the total educational program.

The following have been established by the Board of Regents as desirable goals for the elementary, secondary, and continuing education programs in New York State:

1. Mastery of the basic skills of communication and reasoning.
2. Ability to sustain lifetime learning.
3. Ability to maintain one's mental, physical, and emotional health.
4. Understanding of human relations.
5. Competence in the processes of developing values.
6. Knowledge of the humanities, social sciences, and natural sciences.
7. Occupational competence.
8. Knowledge and appreciation of our culture.
9. Understanding of the processes of effective citizenship.
10. Knowledge of the environment.

Instructional programs in science can and should contribute significantly to the "basic skills" and "values" goals rather than narrowly emphasize the "knowledge" goal.

A laboratory investigation is an ideal activity to facilitate the application of the processes, logic, and skills of science. Science teachers should select experiences which provide a sequential development of the cognitive and manipulative skills of science. Completing the reports which are a culmination of such activities should require the collection and interpretation of data, and related conclusions which provide an experiential base for developing writing skills. Conversely, experiences in writing can help develop scientific insight as well as reinforce the understanding and retention of science concepts.

The publication is designed to help integrate the skills of composing (writing) with the procedures and perspectives of science. Sections are devoted to the composing process and its relationship to the science laboratory model, to techniques for evaluating writing, and to the spectrum of laboratory activities.

SPECIAL MESSAGE TO THE PRINCIPAL

The information provided in this publication, Reflections on Writing in Science, should assist you and your staff in improving a component of the laboratory program that may have been overlooked -- the written laboratory report.

As suggested in the INTRODUCTION, the laboratory should be an important part of each of the science courses in grades 7 - 12. In addition, each of the four Regents science courses has a mandated requirement of laboratory work. (Rules of the Board of Regents, Section 8.2 (c):

> "Only those persons who have satisfactorily met the laboratory requirements as stated in the State syllabus for a science shall be admitted to a Regents examination in such science.")

"The Science Letter, Laboratory Exercises" (NYS Education Department, September 1972), points out the need for your active support in this matter. Local school officials have the responsibility to establish criteria for laboratory experiences and to determine whether a student has met the laboratory requirement.

Each New York State Regents science syllabus has been developed for a minimum of six, 40-minute periods per week of instruction, or its equivalent. Inasmuch as each State science syllabus places a strong emphasis on the development of laboratory skills, the minimum time allotment should include at least one double period per week. However, the Department recommends seven periods per week with two double periods for laboratory work. (The intent of "equivalent time" is to permit flexibility. Longer or shorter laboratory experiences may be desirable depending upon local situations. Thus, the minimum laboratory requirement can be met by doing 30 exercises requiring 30 laboratory periods. It can also be met by spending 30 laboratory periods on a smaller number of investigations.) Able students should be encouraged to spend additional periods on extended problems which go beyond the required investigations.

Inasmuch as an effective laboratory experience is a fundamental component of any science course, the teacher must communicate effectively and regularly with the student and parents:

- At the beginning of the school year, students and parents should be informed of the criteria for adequate laboratory experiences in science courses. In September, some administrators send copies of the rules governing

laboratory work to the parents with a place for a parent's signature. These forms are then filed for the rest of the school year.

- At the beginning of the year each student should be given a list of the particular laboratory investigations for the year which indicates how much time is allotted for each laboratory experience. The same list could be posted in the science room.

- After a student completes a written laboratory report, it is evaluated. If a student has successfully completed the report, credit is recorded on a locally designed management chart. An unsatisfactory report should be returned to the student for revision.

S = Satisfactory U = Unsatisfactory	Name of Laboratory Exercise: Safety Procedures in the Lab	Observing a Floating Ice Cube	Field Trip to the Stream	Controlling Variables	Etc.	
Number of Periods/Lab	2	1	3	1		
Student #:						
12001	S	S	S	S		
12002	S	U		U		
12003	S	U	S			
Etc.						

- If a student is not making satisfactory progress towards the State mandate of 30 laboratory periods with successfully written reports, the parents should be notified at regular intervals (possibly at the middle and/or end of marking periods). This action will help prevent any last-minute debates in June with parents and/or the student as to whether the student will be allowed to take a Regents science examination. This regulation applies to all students, whether regularly enrolled in a Regents science class or studying independently. For students with severe handicaps, admission to science Regents examinations will be considered on an individual basis. (Contact the Chief of the Bureau of Science Education, NYS Education Department, Albany, NY 12234.)

THE COMPOSING PROCESS

Science involves a process, an approach for acquiring knowledge and ideas; writing is one process of communicating that knowledge to other persons. Because science and writing can interact with each other (if given the opportunity), it is advantageous to integrate these two important processes so that each will reinforce the other.

It should be noted that a current focus in language arts education is upon the activities of the composing (writing) process rather than on the written product only. Although different writing programs use various words to identify the stages of the composing process, the stages can be synthesized to include three fundamental parts:

1. Prewriting
2. Writing
3. Revising

Prewriting

"How do I know what I think until I see what I say?"

E. M. Forster

The Prewriting stage of the composing process is the activity which prepares the student to synthesize or extrapolate experiences and knowledge through writing. Inasmuch as these activities are performed before the student begins a rough draft, they are considered prewriting even though they also may involve the physical act of writing.

Some of the individual student prewriting behaviors may include the following:

- Observing
- Reading
- Organizing
- Clustering
- Interviewing
- Researching
- Note taking
- Outlining

Science teachers should motivate their students and supply them with some organization of information prior to starting the laboratory experience by arranging various homework and/or class prewriting exercises such as:

- Clustering previous knowledge
- Watching films
- Observing demonstrations
- Completing worksheets
- Brainstorming new ideas
- Conducting lab activities

Prewriting activities expand the student's awareness of the problem to be investigated in the laboratory, and assist greatly in making the laboratory experience a successful one. A well-designed prewriting experience will help the student acquire new insights during the writing stage.

Writing

> "Writing has got to be an act of discovery...I write to find out what I'm thinking about."
>
> Edward Albee

The Writing stage of the composing process incorporates the use of the written language to synthesize all the activities conducted during the prewriting exercise. In this second stage of the composing process, the insight should be captured in a rough draft. It is important that the student realize that the first draft is not the final product, but merely a starting point. The content and meaning of the message which the student creates and is attempting to communicate become the fulcrum of the composing process.

Within the context of science laboratory activities, "writing" includes more than the physical act of putting words on paper. Rather, "writing" includes the transforming of data into charts, tables, graphs, or formulas; the formulating of relationships; the analyzing of experimental hypotheses; and the generalizing of conclusions. The teacher or the student manual may require that the student use a particular report form. Therefore, the student is faced with the task of assimilating and restructuring the myriad types of data and ideas into one acceptable composite report.

The following advice should be of help to a student writer beginning a first draft.

1. Set aside a period of uninterrupted time.
2. After starting, don't stop for 15 to 20 minutes.
3. Capture the ideas; defer concern for syntax or grammar.
4. Find the main idea which you want to communicate in your report.
5. Expand the most interesting ideas.
6. Select and arrange sentences or fragments into a rough draft.
7. Add statements for transition or emphasis.

Now the significance of the last stage, Revising, becomes apparent: the teacher is obligated to provide an opportunity for the student to "rework" the writing before accepting the final report.

"As you continue writing and rewriting,
you begin to see possibilities you hadn't
seen before."

Robert Hayden

When the first draft is completed, Revising begins. This stage of the composing process is devoted to improving the content and form of the message found in the rough draft. The primary concerns for the student to focus upon are the logic of the presentation, the appropriateness of the supporting evidence, and the clarity of expression. The student must scrutinize details ranging from the major organization of the report to the sequential development of the main idea. Frequently, certain sections require restructuring or reformulation in order to give the meaning intended. On the other hand, the student might reject the entire first draft and produce a new rough draft.

The next step in the Revising process is to correct errors related to language mechanics such as spelling, grammar, punctuation, capitalization, or syntax. In addition to these editing tasks, the student should improve the effectiveness of the report by attending to readability, format, copy (handwritten or typed), neatness, and headings.

Conferences of small groups of students are an effective means of revising the rough draft. Students can be effective editors for a host of problems which plague a student's first draft. Given the basic guidelines that the criticism must be focused, not general; positive, not ridiculing; and concretely expressed, students can train themselves rather quickly to improve their writing. Copies of the proper report format and various types of revising checklists should be available for direct comments. A typical checklist for content and form can be found in the section on Techniques for Evaluating Student writing (page 16). Finally, the student must be convinced that the work in this revision process will be rewarded by the feedback of peers or teachers and by the subsequent evaluation of the final report.

A LABORATORY ACTIVITY MODEL

The Laboratory Activity Model which follows is adapted from the work of Lunetta and Tamir (1979). Although the model does not include all of the skills considered important by science teachers, it illustrates the progressive levels of common experiences available to students during a laboratory investigation. Not every laboratory activity will include all of the indicated behaviors; however, a laboratory program should have a variety of activities through which the student experiences all the behaviors.

LABORATORY ACTIVITY MODEL
(Adapted from Lunetta and Tamir, The Science Teacher, May 1979)

1) Planning

Formulates questions
Defines problems
Predicts results
Formulates hypotheses
Designs procedures
Designs experiments

2) Performance

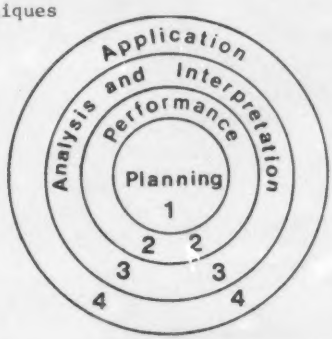
Performs qualitative observations
Performs quantitative observations
Manipulates materials
Records and describes
Calculates
Explains techniques

3) Analysis and Interpretation

Transforms data
Graphs data
Determines qualitative relationships
Determines quantitative relationships
Analyzes for errors
Explains assumptions

4) Application

Predicts in new situations
Formulates new hypotheses



In some cases, one completed activity can provide the skills, concepts, and unanswered problems for the next activity; thus, one entire experience becomes a portion of the "planning core" leading to the next laboratory experience. The model outlines a progression of skills and operations toward a final product, with each ring including procedures at a higher level of cognitive functioning than the inner ring adjacent to it. This is consistent with Gagné (1963, page 31), who offers this analysis:

> "Knowledge is a hierarchy of ideas in which more complex ones depend for their acquisition on the previous mastery of simpler ones. Thus, when a curriculum designer has in mind a set of ideas he wants students to acquire, he must ask himself very systematically, 'What must the student already know how to do, in order that he can acquire this new knowledge?...' Unless a student can progress regularly from one idea to the next, we lose him."

Planning

Typically, planning defines the pre-laboratory situation. It involves the consideration of a large number of possible activities from which the teacher selects those which can best present the concepts, problems, skills, techniques, terminology, or past experiences which apply to the objective at hand. Involvement in this planning phase may include such diverse activities as teacher or student demonstrations with apparatus; reading the laboratory procedures; or focusing appropriate questions or open-ended discussions during which the students formulate their own hypotheses and experimental design.

Performance

Performance, as the title suggests, is the actual execution by the students of the planned activities. Observations, whether qualitative or quantitative, are made as the students describe, record, manipulate, calculate, or explain situations occurring during the actual operation of the activity.

Analysis/Interpretation

After the Performance section of the activity, the students must use cognitive skills to transform the data into tables, diagrams, graphs, or equations which permit qualitative or quantitative analysis. The students may explain the assumptions underlying an interpretation or develop statistical comparisons of errors or probabilities. Or, in a highly structured lab situation, the students may follow a prescribed set of sequential directions leading to a definite endpoint, and summarize using individual or class data and responses.

Application

During the Application phase, the students should make a transition from the laboratory experience under Analysis to contemporary or future problems. As the students complete the final written report during the post-lab activity, they should be guided either by the teacher, peers, or themselves to become increasingly aware of a major characteristic of science: solving one problem or question always leads to new questions. The students should be encouraged to predict whether the principle under study may apply to a new situation, and to state such a prediction in terms of a testable hypothesis. The students might also consider the value of convincing the scientific community that further investigation is merited, or generalize about the usefulness of the problem to humans.

INTEGRATING THE LABORATORY ACTIVITY MODEL WITH THE COMPOSING PROCESS

The science laboratory report employs the composing (writing) process in order for the students to communicate the new scientific insight acquired from the laboratory exercise.

The Laboratory Activity Model progresses in a logical sequence or hierarchy of skills: Planning, Performance, Analysis and Interpretation, and Application. Even so, not all laboratory exercises include all of these phases. When the goal is mastery of a particular technique, for example, Analysis and Application may be an inappropriate expectation. Hopefully, the science program is designed to use this technique during a subsequent laboratory experience in which related higher level skills may be addressed.

In contrast, the writing process is more flexible. Every writing experience should culminate wit a finished product. Any introductory activity initiates the Prewriting stage which is followed by Writing the draft, and Revising. The quality and the emphasis found in the final product depend upon the activities and structure the teacher provides. Here lies the compelling reason for integrating science and writing: science teachers create an ideal environment for writing with the laboratory experience, and writing is the perfect vehicle for communicating the meaning of the experience.

- Prewriting exercises such as brainstorming, clustering, selecting, and organizing are easily seen as facets of Planning and Performance, such as: defining a problem to investigate, predicting results, designing how to measure the results, and recording and describing the results.

- Writing the first draft may be an incomplete, disjointed combination of those Planning and Performance phases, but the intended concept to be learned should be there, somewhere. As the student begins to examine the data in the rough draft, more interactions between science and the composing process become evident. Analysis and Interpretation involves transforming the data into charts, graphs, and tables, from which qualitative and quantitative relationships can be made. In the rough draft, there may be incomplete or unfinished graphs, initial copies of diagrams, and both applicable and irrelevant formulas and associations. This is unacceptable as a final report, but the ideas are there for consideration and refinement. Whether from a lab partner, teacher, unfinished tape, or the next step in the

laboratory manual, the student seeks feedback at this juncture. "Am I on the right track?" "Did the formula work?" "How am I doing?" "Did you get what I found?" "Where? I don't see that." Proper guidance answers these questions and the Revising process begins.

- Revising requires that the student focus upon the main idea, expand and interrelate supporting ideas, exclude irrelevant detail, and arrive at some conclusion which illustrates that the concept has been learned. The student may also suggest applications to new situations or new questions. The final report needs polishing for proper mechanics, labeling, titling, and illustrating. Readability and format are also considered in the evaluation of the report.

TECHNIQUES FOR EVALUATING STUDENT WRITING

Evaluation by the Teacher

Science teachers have frequently expressed their concern about the lack of time available for them to evaluate adequately their students' laboratory reports. This is unfortunate, in light of the fact that the amount of science which has been learned, or has not been learned, from the laboratory experience can often be determined from the report.

This "lack of time" is not unique to science education, however. Because English teachers have had to contend with the burden of student essays and research papers, they have developed several valid techniques to deal with the time problem. Science teachers can benefit from applying these techniques.

Some commonly used teacher methods for evaluating student writing are: holistic evaluation, primary trait evaluation, and analytic evaluation. Each of these methods has its advantages and its disadvantages. The teacher should use the type of evaluation which is appropriate to the objective for the particular writing assignment.

- Holistic evaluation allows the teacher to go through many reports in a short period of time, in a method as reliable as any for evaluating students' writing. Basically, the teacher reads quickly through a student's complete report (without concern for such items as spelling, punctuation, etc.) and evaluates it on the basis of the first impression of the work as a whole, both in content and form.

  Although the holistic method saves teacher time, it does not provide much feedback to the student in terms of all the possible errors that might occur during the writing process. However, this method will enable the teacher to determine that the student has conducted the investigation and has a general understanding of the outcome of the investigation. This will provide a basis for the teacher to quickly assess whether the report should be rated as acceptable or unacceptable.

- Primary trait evaluation is a method in which the teacher examines only one or two selected characteristics of the report. During the pre-laboratory discussion, the teacher may choose to identify for students the specific trait(s) of the report upon which he/she will be focusing; e.g., whether the

student had an adequate control in the experimental design in the laboratory and addressed the content in the report. A rating system for evaluating this trait might be:

Adequate control included	3
Adequate but incomplete control	2
Inadequate control	1
Control not included	0

Other items that may be used for primary trait evaluation can be found in the Checklist for Revision and Evaluation of the Written Report: Content and Form (page 16).

The primary trait evaluation method saves time (although not as much as the holistic approach) since the teacher does not comment on all elements of the writing process as well as the scientific processes and content. The student benefits from primary trait evaluation in that he/she focuses on specific skills that need improvement. Also, primary trait evaluation is especially effective with poor writers. Instead of filling a paper with red ink, thus discouraging both the student and the teacher, the teacher can work with the student on improving one particular aspect of the writing and/or the science.

- Analytic evaluation involves a comprehensive technique for evaluation: a careful analysis of the entire report's strengths and weaknesses in content and form, both specific and general, with extensive comment by the teacher throughout the report. Items that may be reviewed are:

Content	Form
Formulated Hypothesis	Organization of Report
Identified Variables	Selection of Vocabulary
Included Adequate Control	Sentence Structure
Described Observations	Mechanical Skills
Interpreted Observed Data	Graphing Techniques
Applied Prior Knowledge	Diagrams and Labels
Applied Information to New Situations	

Needless to say, this method is very time-consuming; however, it enables the teacher to reward the student's efforts with careful, focused attention. It is especially useful with better writers who need to perfect the precision and clarity of their writing.

Evaluation by Peers

Science teachers should also turn to students to help in the evaluation process. Peer evaluation can serve as a useful tool in the Revising stage of the composing process. At its simplest level, peer evaluation may involve merely the exchanging of papers and the answering of one good question about the meaning or effectiveness of a portion of the report. At its best, peer evaluation can provide the students with a good deal of constructive criticism and positive comment from the people who mean most to them -- their fellow students. The evaluation can be done during the Revision stage using an Analytic approach, which is the most time-consuming method for the teacher. In it, the students help each other find weaknesses and correct them. Peer evaluation can also be employed effectively on the day the paper is to be submitted to the teacher, through a small-group, round-robin procedure, in which four or five students comment on each report. When the papers have been commented on by all members of the group, each writer can read aloud the comments about his/her paper, and a free discussion is possible within each group. If the students like and trust each other and a suitably purposeful tone has been established, such a procedure can be tremendously effective. It must be emphasized to the students that peer evaluation requires criticism that is positive and constructive. Although the students do not replace the teacher evaluation, a student can gain much from this activity. Incidentally, evaluation also improves the peers' insights as well!

Self-Evaluation

Self-evaluation is a technique that must be stressed because it reminds the students that the evaluation of their writing is, finally, their own responsibility, and it teaches them how to do it. Too often, unfortunately, a post-laboratory activity consists merely of the students' completing their laboratory reports and immediately handing them in. If the teacher returned the papers the next day and allowed the students to review the writing, they might discover oversights themselves. Most students like self-evaluation, once they get used to it, because it allows them to communicate with the teacher their feelings about their writing.

The following Checklist for Content and Form was developed to serve several functions. The teacher or the students may use the entire checklist for Analytic evaluation or particular sections to direct attention to a particular Primary Trait. Even if only used for discussion purposes, the checklist provides a detailed reminder to the students about the elements of content and form which are important to effective communcation.

CHECKLIST FOR REVISION AND EVALUATION OF THE WRITTEN REPORT: CONTENT AND FORM

	Accept-able	Not Acceptable	Does Not Apply
CONTENT:			
I. Planning			
1. identifies a problem or question to investigate			
2. formulates hypotheses			
3. explains or refers to experimental design			
4. plans appropriate controls			
II. Performance			
1. demonstrates knowledge of technique			
2. describes and observes accurately and completely			
3. demonstrates quantitative measurement			
4. identifies dependent and independent variables			
III. Analysis and Interpretation			
1. appropriately transforms raw data			
2. correctly interprets observed data			
3. shows qualitative relationships			
4. show quantitative relationships			
5. analyzes accuracy of data			
6. suggests limitations or assumptions affecting data			
7. proposes a generalization or model			
8. justifies conclusions			
IV. Application			
1. integrates prior knowlege			
2. suggests original hypotheses			
3. suggests contemporary application			

	Accept-able	Not Acceptable	Does Not Apply
FORM:			
I. Mechanical Skills			
1. spells correctly			
2. punctuates correctly			
3. capitalizes correctly			
4. writes legibly			
II. Word Choice			
1. uses words correctly			
2. uses appropriate vocabulary			
3. uses clear, concrete language (without slang)			
III. Sentence Structure and Syntax			
1. varies sentence structure			
2. uses complete sentences (without fragments or run-ons)			
3. keeps subject/verb in agreement			
4. appropriately uses conjunctions			
IV. Graphic Techniques (for Diagrams, Tables, Charts, and Graphs)			
1. draws accurately			
2. adapts constructions to fit conventions			
3. labels correctly			
4. presents visually effective data			
5. matches captions to data			
V. Organization of the Lab Report			
1. composes internally consistent paragraphs			
2. reorganizes paragraphs into sections			
3. forms transitions between ideas			
4. summarizes and concludes major ideas			
5. articulates and coordinates a coherent model			
VI. Understanding the Lab Activity (See also Content)			
1. follows format directions			
2. focuses upon topic			
3. excludes irrelevant material			
4. supports generalizations with appropriate examples and detail			
5. demonstrates understanding of the objective			

As an aid to getting started in evaluation, the following considerations should be helpful.

1. Select the appropriate evaluation technique: Holistic, Primary Trait, or Analytic.
2. Make clear to the student the specific criteria for evaluation to be used.
3. Possibly use two grades -- content and form; or sections from within the checklist.
4. Include positive responses.
5. Realize that grades are subjective.
6. Use peer evalution and group discussions.
7. Return papers quickly.
8. Accept no paper that is sloppily done.
9. Distribute a list of editing symbols. Example:

⊙ insert period	⨍ delete
↑ insert comma	∽ transpose letters
⊂ close up	(tr) transpose words or symbols
¶ paragraph	lc use lower case
no ¶ no paragraph	≡ use capital letter

In the past, many teachers have limited their reaction to the report to a final critique or "summative evaluation," which often is part of the grading process. The composing process can benefit greatly if "formative evaluation" is also used. This involves the ongoing process of evaluation and re-evaluation which proceeds throughout the stages of Prewriting, Writing, and Revising from the time students begin organizing their thoughts to the time they finish their final copy.

SPECTRUM OF LABORATORY ACTIVITIES

In the late 1800's, laboratories for instruction in science were constructed in the secondary schools of the United States. At that time, the "recitation" approach to learning science began to be supplemented with "experiments" having the expressed purpose of verifying the laws of science (Sund and Trowbridge, 1967). As early as 1910, improvements recommended for science courses included increased emphasis on "reasoning out" rather than memorization, and more attention to developing a "problem-solving attitude" and a "problem-raising attitude" on the part of students. However, science curriculum and laboratory work showed little or no change until the curriculum reform movement of the late 1950's and early 1960's.

This new role of the laboratory in teaching secondary school science was expressed then as:

> "The laboratory setting is unique among the various environments that young people encounter in their schooling; it is a peculiar possession of science instruction. It is a place where students can investigate natural phenomena in an immediate or first-hand experience and apply various cognitive skills towards an interpretation of these phenomena... This, then, is the rationale for the laboratory experience in which the student can learn to appreciate the scientist as a person fulfilling a role in society; he/she can engage in 'sciencing,' generally, as a student, in developing more systematic and orderly ways of thought..."
>
> O. R. Anderson, (See page 27.)

In the early 1960's, science educators such as Pella (1961) and Strickland (1964) analyzed the content and structure of science laboratory manuals. Twenty years later, Lunetta and Tamir (1979) also analyzed them, and reported findings surprisingly similar to Pella's and Strickland's.

Despite two decades of curriculum reforms in science education, many students are still engaged in getting a "right answer" in the "right blank" on the "right line." Today's students are seldom given opportunities to discuss sources of experimental error, to formulate hypotheses, to design and actually perform experiments, and to derive applications (Lunetta and Tamir, 1979). Instead, the students are asked to follow explicit instructions which concentrate on the development of lower level skills -- making observations and measurements, recording results, and manipulating apparatus. Too often the conclusions the students expected to arrive at are known to them before the activity begins. Often, the laboratory manual is one which requires that the students repeatedly attempt to verify what the manual says the natural environment is like.

In contrast, there are well-planned, sequential, lab-centered science programs that have been developed and that are available. The National Science Foundation (NSF)-funded curriculum projects have produced courses which provide laboratory investigations in which the students seek outcomes which are not previously known to them. Many publishers of textbooks have responded by incorporating similar investigations in their texts and/or manuals. A three-part series of studies by NSF indicates that there is more use of laboratory and hands-on instruction than before the NSF curricula were developed and implemented. Yet, the predominant method of teaching science continues to be recitation/discussion, followed in frequency by demonstrations. Manipulative laboratory experiences for the students have been observed to be the least-used method (DeRose, et. al., 1979).

There are very important decisions for those who plan the laboratory part of a program of science education. How and when will the students manipulate supplies and equipment? What will be the mix and sequence of verifying activities compared to seeking-information activities? What will be the mix and sequence of laboratory activities in which the students assume a relatively large amount of responsibility for structuring the laboratory instruction as compared with the amount of structure provided by the science teacher?

Manipulative Experiences

The laboratory can be defined as the place where the science students engage in the manipulation of concrete objects. Manipulative activities provide direct experiences for the students and enable them to answer important questions on the basis of personal observation and experimentation.

A recent national survey indicates that the use of manipulative laboratory instruction again appears to be diminishing (Weiss, 1978). Although science teachers use manipulative activities much more than do teachers of social studies, mathematics, and language arts, nationwide 26 percent of the classes in science in grades 10-12 and 38 percent of the classes in science in grades 7-9 do not experience manipulative laboratory activities as often as once a week (Weiss, 1978).

Teachers report that there are many barriers to surmount when they attempt to incorporate or to retain laboratory activity within their science programs. They cite as key barriers inadequate time-blocks in the schedule, shared classrooms, inadequate teacher training, reduced funding, inadequate facilities, and the lack of student motivation. (DeRose, 1979).

Any rationale for continuing to include or for increasing the frequency of laboratory experiences in secondary school science classrooms should include the findings of research. They indicate

that: laboratory experiences are superior for providing the students with skills in working with equipment (Rowe, 1978); and, laboratory experiences when properly conducted enhance retention of knowledge over time (Ramsay and Howe in Rowe). Laboratory experiences also provide information to the student that is almost impossible to convey otherwise. For instance, "... Words and static illustrations cannot capture the complexity of the behavior of micro-organisms in a droplet of pond water, or of the ways in which waves passing through two narrow apertures interact to produce interference patterns." Also, laboratory work demands activity from the student at a time when many young people lead increasingly passive lives. (National Research Council, 1979, page 34.)

The New York State Regents syllabuses in science feature laboratory requirements which express a firm commitment to manipulative laboratory experiences at the senior high school level. Although manipulative activities in science have not been directly mandated for students in the middle/junior high school, the importance of this aspect of the program for these students must not be underestimated. Because a higher percentage of students in the middle/junior high school years are at the concrete reasoning level than those enrolled in Regents science courses, these young students need at least as many, if not more, opportunities for manipulative laboratory work. These students need reference to familiar objects, observable properties, and familiar actions (Rowe, 1978).

When planning laboratory experiences, the teacher should give priority to field and laboratory activities which feature manipulation. Occasionally, however, there are legitimate instances when nonmanipulative activities can and probably should be substituted for these activities. The less direct experiences available through filmloops or videotapes, photographs, or three-dimensional stereograph pictures, teacher demonstrations, and microcomputer simulations can be reasonably substituted when the objects or energy levels are sufficiently hazardous, the events are very lengthy, the activity is excessively costly, the the objects are inaccessible.

Seeking Information

There is a discrepancy between what is said and what is done regarding the students' seeking the answers to questions rather than verifying what they have been told. Surveys indicate that teachers make positive statements about the value of the students' seeking information, yet teachers' actions show that they feel a much greater responsibility for teaching facts (Harms and Yager, 1968). Classroom observers report considerably less time than the 10 percent estimated by teachers is devoted to the students' actively seeking information (Stake and Easley, 1978).

Laboratory investigations have been developed in which the students seek information in order to explain a phenomenon which they do not know in advance. In designing such investigations, the

teacher should take particular care regarding two sections common to laboratory reports. First, if a "Purpose" section appears in the investigation, does it inadvertently state the conclusion of the investigation? For instance, "Purpose: to show that the resultant of two forces is equal to the equilibrant but opposite in direction." For this laboratory activity the students are being asked merely to verify information rather than to seek information that is unknown to them.

The second section for the teacher to focus on is a "Formulation of Hypothesis" section, if one exists. The steps typically found in traditional (verification) laboratory manuals are "Purposes," "Apparatus," "Procedure," "Data," and "Conclusions;" (Pella, 1961), with a "Formulation of Hypothesis" step absent. If the students are required to formulate or test a hypothesis, they are being asked to seek information that is unknown to them.

The intent here is not to suggest that verifying laboratory experiences are never appropriate. Rather, the teacher is encouraged to identify situations for which it is appropriate to have the students seek information, and to provide investigative laboratory experiences for these situations.

Provisions for Structure

Laboratory activities range from the completely unstructured investigation in which everything is done by the students to the activity totally structured by the teacher. If each student is given a blank sheet of paper and then defines a problem, composes procedures, assembles equipment and materials, organizes data and draws conclusions, the student provides all the structure. Here is an example of that situation, except that the teacher has provided an object to manipulate and has posed a question.

> Students come into the physics laboratory, where they find a steel spring and a sheet of paper at their tables. The problem is written on the blackboard. It reads: "What are the characteristics of the steel spring at your table?" This is the extent of the structuring. During that period the students organize their thinking and decide what they wish to do. Some students work on the problem a week; others take six weeks. They determine the harmonic motions of their springs, the tensile strengths, and the influence of temperature. They measure compression forces, strength, fatiguability. ...Much is learned in this "loosely-organized" situation.
>
> (American Biology Teacher, May, 1963)

Contrast that situation with the amount of structure provided in the following situation. Here the problem is given, the procedure is given, the equipment is given, the pattern of organization is given, and even the results (answers) are printed somewhere in the manual!

> How many milliliters of sodium hydroxide in bottle A are required to neutralize 40.0 ml HCl which has .0985 mole per liter of HCl: What is the molarity of the NaOH? NaOH and HCl react on a mole to mole basis. (Details of titration are given... A few arithmetic manipulations follow a few motions of manipulative skills and require only an ability to follow instructions,which in itself is extremely important.)

(American Biology Teacher, May, 1963)

The chart below builds upon the work of Pella (1961) using the laboratory tasks suggested by Lunetta and Tamir (1979). Individual investigations listed vary in the amount of structure assumed by the teacher (T) and the student (S).

Laboratory Skills	Investigations				
	I	II	III	IV	V
1.0 Planning and Design					
1. Defines problem (1.1)	T	T	T	S	
2. Formulates hypothesis (1.3)	T	T	S	S	
3. Designs experiment (1.5)	T	T	S	S	
2.0 Performance					
4. Manipulates apparatus (2.2)	S	S	S	S	
5. Records results (2.3)	S	S	S	S	
3.0 Analysis and Interpretation					
6. Explains relationships (3.6)	T	S	S	S	
4.0 Application					
7. Generalizes to new situations (4.1)	T	T	S	S	

In Investigation I, the teacher performs steps 1, 2, 3, 6, and 7. This is typical of investigations whose purpose is to verify. In Investigation II less structure is provided for the student than in Investigation I. In Investigation III appears the highly unstructured "spring" cited in this section. In Investigation IV there appears the extreme described in this section in which the student is given a blank sheet of paper and takes over from there.

It should be apparent that in science laboratories there exists a wide variety of situations that fall between the two extremes (I and IV). Every investigation performed in the science laboratory can be described by using the ideas presented in the chart. If the teacher makes notes on each investigation on the chart and finds that the same format is used throughout in the laboratory part of the program, he/she may wish to consider revising some of the investigations to provide opportunities for the student to learn to assume increasing responsibility for providing structure as the school year progresses.

GUIDELINES FOR SELECTING LABORATORY MANUALS

A NSF-supported study (Weiss, 1978) found that the primary decision makers in the selection and use of curriculum materials are the classroom teachers. Their influence as members of committees for the selection of instructional materials or as individuals is far greater than that of the superintendent, principal, or district supervisor. Because the success of a laboratory-oriented course of study greatly depends upon the quality of the laboratory manual(s) selected or developed locally, the method used by teachers in the selection/evaluation of laboratory printed materials may indirectly dictate the quality of the students' science experiences.

A review of secondary school science laboratory manuals shows that a wide variety exists from which to choose. Although one system of classification of manuals might be commercially published vs. teacher-prepared ones, it is probably more useful to classify manuals in terms of their meeting or not meeting the objectives of modern programs of science education, regardless of the source of preparation.

Most of the laboratory manuals surveyed stress the Performance phase and the Analysis/Interpretation phase. Noticeably absent are experiences for the student related to the Planning phase and the Application phase. Teachers may need to supplement or modify manuals to provide the students with experiences in these two areas.

The Laboratory Activity Model (see page 8) can be helpful in the process of selecting a laboratory manual which emphasizes student behaviors in the science laboratory:

1. Planning
2. Performance
3. Analysis/Interpretation
4. Application

The following chart by Lunetta and Tamir can be used to evaluate the individual laboratory exercises in the manual and to determine which laboratory skills it stresses. If the chart for all the individual exercises is viewed as a summation, the range of skills developed by the entire manual can be seen. Any one exercise should not be expected to cover all of the subdivisions in the chart; but the manual, as a whole, should cover the various subdivisions.

CHART FOR EVALUATING LABORATORY ACTIVITY

	TASK CATEGORY AND INVESTIGATION NUMBER	LABORATORY / ACTIVITY																				NUMERICAL TOTAL		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	+	0	-
Planning and Design 1.0	1.1 Formulates a question or defines problem to be investigated.																							
	1.2 Predicts experimental results																							
	1.3 Formulates hypothesis to be investigated in this investigation.																							
	1.4 Designs observation or measurement procedure.																							
	1.5 Designs experiment																							
Performance 2.0	2.1 a) Carries out qualitative observation.																							
	b) Carries out quantitative observation or measurement.																							
	2.2 Manipulates apparatus; develops techniques.																							
	2.3 Records results, describes observation.																							
	2.4 Performs numeric calculation.																							
	2.5 Explains or makes a decision about experimental technique.																							
	2.6 Works according to own design.																							
Analysis and Interpretation 3.0	3.1 a) Transforms results into standard form (other than graphical).																							
	b) Graphical results.																							
	3.2 a) Determines qualitative relationship.																							
	b) Determines quantitative relationship.																							
	3.3 Determines accuracy of experimental data.																							
	3.4 Defines or discusses limitations and/or assumptions that underlie the experiment.																							
	3.5 Formulates or proposes a generalization or model.																							
	3.6 Explains a relationship.																							
	3.7 Formulates new questions or defines problems based upon result of investigation.																							
Application 4.0	4.1 Predicts, based upon results of this investigation.																							
	4.2 Formulates hypothesis based upon results of this investigation.																							
	4.3 Applies experimental technique to new problem or variable.																							

KEY: + = instructions call for this student behavior at least once.
0 = instructions are vague and this student behavior may or may not result.
- = instructions do not call for this student behavior.

A review of laboratory activity sheets contained in manuals also indicates a wide range of reporting formats for the students. The least common format is one that provides large amounts of space for the students to create their own responses. The most common response format is a question followed by a "blank space" for students to enter a single word or phrase, followed by more questions with more blanks. This format, in itself, is not necessarily inappropriate. It is essential, however, that the questions be well-designed and provide opportunities that require the students to respond at successively higher reasoning levels. Teachers may need to supplement the "fill-in-the-blank" laboratory report sheet with additional questions and/or space for responses.

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